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ON THE DOUBLE REFRACTION OF LIGHT, ACCORDING TO
THE PRINCIPLES OF FRESNEL.*

It was noticed, in the last number of this magazine, under the head of proceedings of the Royal Irish Academy, that two papers of Mr. M'Cullagh, (a scholar of Trinity College, Dublin, and candidate for a fellowship there,) were to have been read at the June meeting of the academy, and were only prevented from being so, by the adjournment which took place, in consequence of the death of the king. These papers relate, one to the double refraction of light, and the other to the rectification of the conic sections; they had been before referred, in the council of the academy, to a committee, consisting of Dr. Lloyd, Dr. Sadleir, and Professor Hamilton; and in consequence of the favourable report of the committee, they have since been ordered to be printed, and will appear in the forthcoming volume of the Irish Transactions. Although this volume will very soon be published, yet as we have been favoured with a sight of Mr. M'Cullagh's papers, and think them creditable to the university of which he is a member, we shall endeavour to present our readers with a sketch of their subject and plan.

The first of the two papers relates, as we have already said, to the double refraction of light, which is one of the most curious and interesting subjects in mathematical and physical optics. The refraction produced by water has long been known; for Virgil alludes to the *oar broken in the Sicilian wave*; although the discovery of the law of this breaking, was reserved for Snellius and Descartes. But the double refraction produced by crystals, seems to have been unknown to the ancients; the earliest observations on the subject having been published in 1669, by Erasmus Bartholinus, professor of geometry at Copenhagen. Bartholinus found that when a piece of the transparent crystal, technically called carbonate of lime, and more familiarly known by the name of Iceland spar, was laid upon any object, the object was seen *double*; each line or letter, for example, of a printed book, being changed into two such lines or letters, both equally distinct. Huyghens, the great contemporary, and almost rival of Newton, made new experiments upon the subject, and deduced a remarkable law of the phenomena, which he connected, by elegant geometrical reasonings, with his theory of the undulations of a luminous ether. So decidedly was Newton opposed to this theory of luminous undulations, that it seems to have prevented him from giving sufficient attention to any researches which were connected therewith; although he was always ready to admit the great merit of Huyghens, as a geometer and as a physician. At least, this bias against the theory of waves appears to be the only mode of accounting for Newton's having proposed, in one of the celebrated Queries annexed to the third book of his Optics, an inaccurate law of double refraction, instead of that which Huyghens had given; although he had seen the treatise of his contemporary, and alludes to it in another of his Queries. The authority of Newton seems to have prejudiced those who succeeded him, until the experiments of Wollaston confirmed the law of Huyghens, and revived it after a century of oblivion. Herschell, in his Treatise upon Light, (*Encyclopædia Metropolitana*), observes, that since this time, a new impulse has been given to this department of optics; and the successive labours of Laplace, Malus, Brewster, Biot, Arago, and Fresnel, present a picture of emulous and successful

* Mr. M'Cullagh's Papers. (Transactions of the Royal Irish Academy Vol. xvi. Part Second.)

research, than which nothing prouder has adorned the annals of physical science, since the development of the true system of the universe. "To enter, however, (Mr. Herschell continues,) into the history of these discoveries, or to assign the share of honour which each illustrious labourer has reaped in this ample field, forms no part of our plan. Of the splendid constellation of great names just enumerated, we admire the living and revere the dead, far too warmly and too deeply, to suffer us to sit in judgment on their respective claims to priority, in this or that particular discovery, to balance the mathematical skill of one against the experimental dexterity of another, or the philosophical acumen of a third. So long as one star differs from another in glory—so long as there shall exist varieties, or even incompatibilities of excellence—so long will the admiration of mankind be found sufficient for all who truly merit it." In the sentiments thus expressed by Mr. Herschell, we fully concur; and think ourselves, by still stronger reason, excused and forbidden from attempting to decide on the respective eminence of these illustrious names. We shall, however, endeavour to give such brief and popular account of the facts and hypotheses respecting double refraction, as may explain the value of that theory of Fresnel, which Mr. McCullagh, in the paper before us, has sought to illustrate and simplify.

We have already mentioned the obvious and fundamental fact, of objects appearing double, when seen through certain crystals. But in order to derive from the phenomena of nature, the instruction and intellectual exercise which they are fitted to afford, we must not content ourselves with such general and obvious perceptions. We must discriminate the similar from the same; must vary, must measure, must combine; until, by the application of reasoning and invention to carefully recorded facts, we ascend to an hypothesis, a law, a theory, which includes the particular appearances, and enables them to be accounted for and foreseen. Then, when the passive of our being has been so far made subject to the active, and sensation absorbed or sublimed into reason, the philosopher reverses the process, and asks how far the conceptions of his intellect are realised in the outward world. He seeks to extend his hypothesis beyond the facts on which it was founded, and to deduce from it some new appearance which ought to be observed, if his theory be coextensive with nature. He then consults sensation and experiment, and often their answer is favourable; but often too, they speak an unexpected language. Yet undismayed by the repulse, and emboldened by partial success, he frames upon the ruins of his former, some new and more general theory; which, equally with the former, accounts for the old appearances, while it includes, within its ampler verge, the results of more recent observation. Nor can this struggle ever end, between the active and the passive of our being, between the ingenuity of the theorist and the patience of the observer, until the mind of man shall grasp the infinity of nature; and comprehend all the scope and character and habits of those innumerable energies which compose the material universe. Meanwhile this warfare, with its alternate triumphs and defeats, its discoveries of laws and exceptions, forms an appointed discipline for the human mind, and its history is justly interesting. And in no part of physical inquiry, has the struggle been more vigorous and various, than in the research of the phenomena of light. In astronomy, Newton, by one great stride of thought, respecting the law according to which the heavenly bodies act upon each other, placed theory at once so far in advance of observation, that the latter has

not even yet overtaken the former, nor has the law of gravitation, in all its wide dominions, yet met with one rebellious fact in successful revolt against its authority. But in optics, no theory sits thus upon an old ancestral throne. The very nature of light, and the mode of its propagation, have been the subjects of a lengthened controversy. The theory that light, like sound, diffuses itself in waves, which had been maintained by Huyghens, and combated by Newton, is now, after a long interval of neglect, again acquiring defenders, and gaining ground in scientific opinion. And to return to the more immediate subject of the present article, the opinions respecting double refraction have undergone a great and recent change, in consequence of the researches of Fresnel.

To give an idea of this revolution of opinion, we must distinguish between the phenomena of *single-axed* and *double-axed* crystals; and for this purpose we shall borrow Mr. Herschell's illustration of the meaning of axes of a crystal. "Suppose a mass of brick-work, or masonry, of great magnitude, built of bricks, all laid parallel to each other. Its exterior form may be what we please; a cube, a pyramid, or any other figure. We may cut it (when hardened into a compact mass,) into any shape—a sphere, a cone, a cylinder; but the edges of the bricks within it will still lie parallel to each other; and their directions, as well as those of the diagonals of their surfaces, or of their solid figures, may all be regarded as so many *axes*, that is, lines having (so long as the mass remains at rest,) a determinate position, or rather *direction* in space, no way related to the exterior surfaces, or linear boundaries of the mass, which may cut across the edges of the bricks in any angles we please. Whenever then we speak of fixed lines, or *axes of*, or *within*, a crystal, we always mean directions in space parallel to each of a system of lines drawn in the several elementary molecules of the crystal, according to given geometrical laws, and related in a given manner to the sides and angles of the molecules themselves. We must conceive the axis, then, of a crystallized mass, not as a single line having a given place, but as any line whatever having a given *direction* in space, that is, parallel to the *axis of each molecule*, which is a line having a determinate place and position within it." We may add that the directions of those axes of a crystal which have important optical properties, are usually connected in a regular manner with the planes in which the crystal is found to cleave most easily, or with the other fixed planes or lines which the facts of crystallography indicate. For example, in the case of Iceland spar, the natural or primitive form appears to be that of a regular rhomboid, with six plane faces, and eight corners, of which two are blunter than the rest, and are opposite to one another; and the line that may be conceived to go within the crystal, from one of these corners to the other, is called by mineralogists the primitive axis of the crystal. And the same line is said to be the optical axis also, for the reason which we are going to mention.

When we look perpendicularly down upon any object, through a piece of common glass with two parallel horizontal faces, as for instance, when we lay upon a book a part of a window pane, or a cube of glass, we not only see the object single, but we see it exactly under us. But when we look in the same manner at an object, through a piece of Iceland spar, *one of the two images* which (as was before remarked) we *almost always* see, is not exactly under us; and thus the light which forms this image has undergone an *extraordinary refraction*, since it has come obliquely through the crystal to the eye, while in the ordinary mode of refraction (such as takes place with ordinary refracting sub-

stances,) it would have come perpendicularly through. However there is *one case* in which this extraordinary refraction *disappears*, namely, when the two plane faces of the crystal, through which we are supposed to look, have been artificially obtained, by cutting off the two bluntest corners of the primitive form, in directions perpendicular to the line that joins those corners; for then, that is when we look perpendicularly down through the crystal in the direction of its primitive axis, we see but *one image* of the object below, and that one *perpendicularly under us*.

Analogous phenomena are observed in other crystals. In each there is at least *one optical axis*, distinguished by the property that along it there is *no double refraction*. To all such crystals the law of Huyghens applies. But there are other crystals, more recently discovered, which possess *two optical axes*, distinguished by the same property. To these latter crystals the law of Huyghens is inapplicable, and many attempts had been made to find another which should replace it. In the course of these attempts, many valuable theories were discovered, respecting the connexions between the two separate rays produced by the double refraction. But it was always *taken for granted* that *one* of the two rays followed that law of *ordinary refraction* which Snellius and Descartes had long since established for the passage of light through water and glass, and which Huyghens had found to extend to one of the two rays produced by a single-axed crystal. Fresnel, however, has *overthrown this supposition*, by his experiments upon prisms of topaz, and by other experiments and reasonings; and has thus produced that great revolution of opinion to which we have before alluded.

Nor is this change of opinion confined to the rejection of a law which had been extended by a too hasty induction from single-axed to double-axed crystals. The whole theory of the motion of light has undergone a change, in consequence of the researches and speculations of Fresnel. On the ruins of old hypotheses, he has erected a new one, which may indeed itself be overthrown or changed hereafter, but which will, probably, long continue to guide the thoughts of mathematicians, and the experiments of the physical observer.

The sketch (or at least the notice) which we have thus endeavoured to give, of the optical labours of Fresnel, is indeed a rapid and imperfect one; yet it may serve to give an idea of the nature and importance of those labours, and so may explain the *subject* of that memoir of Mr. M'Cullagh, in which the latter mathematician has chosen to be a commentator on the former. With regard to the *plan* of the commentary, we can only mention here that Mr. M. has aimed, and (we think) successfully, to simplify, by the use of geometrical reasoning, and by several elegant lemmas upon the properties of ellipsoids, the proof of some theorems respecting the shape of the luminous waves, and the positions of the planes of polarization, in the double refraction of light, to which Fresnel had arrived by long analytic processes.

We must be still more brief in our notice of Mr. M'Cullagh's other paper, which relates to the rectification of the conic sections, and contains a geometrical demonstration of a celebrated theorem of Landen, respecting the connexion of hyperbolic and elliptic arcs, which had before been proved by means of definite integrals, in an entirely different manner. It is evident that Mr. M. wields, with no common skill, the ancient armour of geometry. Those who have compared the synthetic and the analytic methods, have usually concluded that the latter is fitter for the discovery, and the former for the communication of truth.

Perhaps, however, as algebra is now employed so often as a mode of elementary exposition, the powers of geometry may not have been exhausted as an instrument of high investigation. In the papers which form the subject of our foregoing notice, Mr. McCullagh has, on the whole, sought rather to illustrate known theorems by elegant geometrical demonstrations, than to open for himself a field entirely new; since, though the method which he uses, and most of the steps, are his own, yet the grand results had before been obtained by others. But he has given a favourable omen that he may hereafter apply his facility of geometrical conception, not only to illustrate but to discover. Let us, therefore, hope that he will aim at this brilliant union; and we, though ourselves devoted analysts, shall attend him with the sincerest good wishes, and give him our most cordial applause.

W.

A FAREWELL.

I could not see thee on thy bridal day,
 I could not mingle with the festal throng;
 Though not perchance less fervently than they
 I wished thee richest bliss, unmixed and long—
 But not at once are quelled those feelings strong,
 Which held entire dominion o'er the mind,
 Nor high resolve hath power, nor charm of song,
 At once the wounded spirit to upbind,
 Or do the trace away that love hath left behind.

To me thou canst not be what thou hast been—
 The polar star in Hope's high firmament—
 The fount that made life's desert pathway green—
 The spell that bound me wheresoe'er I went;
 The treasure of my musings, the dream blent
 With many a rainbow hue of far delight,
 O'er which my fancy but too fondly bent;—
 The prize my young ambition to invite—
 The one dear thought that tinged all else with its own light.

Seldom, how seldom! shall we meet again,
 And stranger-like, and part as strangers part;
 I shall, perhaps, be quite forgotten then,
 And chilled may be this once impassioned heart.
 Yet though no more my star of hope thou art—
 My spring of loftiest, sweetest fantasy—
 Thy cherished image never shall depart,
 Still will I wish all joy to wait on thee,
 Still pray thy lot on earth a younger heaven may be.

W. R. H.